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A New Treatment of Periodic Systems with Applications to Helicopter Rotor Blade Dynamics

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13. ABSTRACT *(Maximum 200 words)*

A computational facility, called the "Nonlinear Systems Research Laboratory", totally dedicated to the dynamic analysis and control of linear/nonlinear mechanical systems with periodically varying parameters has been established. The main items include SUN desktop workstations, an IBM 486DX2/66 personal computer, a laser printer and some necessary software.

This research equipment is being used to develop new practical computational tools for bifurcation analysis and control of nonlinear dynamical systems which give rise to differential equations with periodic coefficients. These new strategies are applicable to general nonlinear time-periodic systems and can be applied to relatively large-scale problems. Unlike some of the existing techniques, such as perturbation and averaging, these methods would be free from small parameter limitations.

The practical significance of this research are being demonstrated through applications of some typical engineering problems including the controller designs for a helicopter blade, a robot undergoing bifurcations and an asymmetric magnetic rotor-bearing systems, among others.

The SUN desktop workstations are used to perform the tremendous amount of numerical and symbolic computations required for this research work. The 486 PC and the laser printer are used to produce quality reports, graphs and research papers for proper dissemination of results on time.

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ARO GRANT NO. DAAL04-93-G-0452

TITLE: **DEVELOPMENT OF NEW STRATEGIES IN DYNAMIS AND CONTROL OF TIME PERIODIC SYSTEMS**

(Contract Period: September 1, 1993 - May 31, 1995)

PRINCIPAL INVESTIGATOR

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Final Report
July 27, 1995

Summary

A computational facility, called the "Nonlinear Systems Research Laboratory", totally dedicated to the dynamic analysis and control of linear/nonlinear mechanical systems with periodically varying parameters has been established. The main items include SUN desktop workstations, an IBM 486DX2/66 personal computer, a laser printer and some necessary software.

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List of Equipment

Hardware:

Quantity	Description
1	S20TXI-612-64-P46 PSARCSYSTEM 20 MODEL 612 WITH TWO 60MHZ SUPERSPARC PROCESSORS WITH 1-M6YTE SUPERCACHE TURBOGX 1-MBYTE FRAME BUFFER COLOR WORKSTATION 20-INCH COLOR MONITOR, 64-MBYTE 1.05-GBYTE INTERNAL FAST SCSI-2 DISK
1	X560A INTERNAL TRIPLE DENSITY FLOPPY DISK DRIVE
1	K981A AUT ADAPTER CABLE

1	X164P 64-MBYTE MEMORY EXPANSION (64-MBYTE SIMM)
1	X6494 1.05-GBYTE FAST SCSI-2 INTERNAL EXPANSION DISK FOR SPARCSTATION 20
1	X3540A TYPE 5 COUNTRY DIT PART NUMBERS FOR SYSTEMS EXCEPT FOR CLASIC, CLASSIC X AND LX. US UNIX
1	820TX1-514-64-P46 SPARCSYSTEM 20 MODEL 514 WITH FOUR 50MHZ SUPERSPARC PROCESSORS WITH SUPERCACHE TURBOGX 1-MBYTE FRAME BUFFER COLOR WORKSTATION WITH FOUR CPU'S 20-INCH COLOR MONITOR, 64-MBYTE 1.05-GBYTE INTERNAL FAST SCSA-2 DISK
1	X560A INTERNAL TRIPLE DENSITY FLOPPY DISK DRIVE
1	X981A AUI ADAPTER CABLE
1	X3540A TYPE 5 COUNTRY KIT PART NUMBERS FOR SYSTEMS EXCEPT FOR CLASSIC, CLASSIC X AND LX UP UNIX
1	X264P 64-MBYTE MEMORY EXPANSION (64-MBYTE SIMM)
1	X649A 1.05-GBYTE FAST SCSI-2 INTERNAL EXPANSION DISK FOR SPARCSTATION 5 AND SPARCSTATION 20
1	XG22A 5 GB, 4MM TAPE
1	IBM PC - MODEL 433DX 2 (527MB, 4MB, 1.44MB, 66Hz) (W/DOS & WINDOWS 3.1) AND MOUSE
1	IBM-6319 15" MULTISYNCH SVGA 1024X768 DISPLAY 28 UM WITH CONTROLS
1	16 MB MEMORY 51MM, 5¼" DRIVE
1	4M PLUS HP LASER PRINTER

Software:

IMSL FOR SUN & PC, MATLAB FOR PC, MATHEMATICA FOR SUN & PC, WP6.1A, FRAMEMAKER, TSI DYNAMICS AND TSI CONTROLS FOR PC

Purpose

'Nonlinear Systems Research Laboratory' is devoted toward developing vibration and bifurcation analysis of time-periodic systems analogous to existing techniques for the time-invariant systems. Another important outcome associated with this development is in the design of linear, nonlinear controls, and control via order reduction specially for large-scale systems. These developments are based on the application of the Liapunov-Floquet transformation matrix. The following are some of the anticipated contributions where this laboratory would be invaluable.

a. Provide tools for the analysis of nonlinear time-periodic systems, such as time-dependent normal form and center manifold theories.

b. Obtain bifurcation diagrams for practical nonlinear time-periodic engineering systems using time-dependent methods.

c. Develop control methods for large-scale linear time-periodic systems via order reduction. Also, develop methods of modal control for time-periodic systems.

d. Utilize bifurcation theory to design linear/nonlinear controllers for periodic systems.

e. Address robustness characteristics of such control designs.

f. Demonstrate applications to a number of practical engineering problems.

The above problems are currently being investigated under the following projects supported by the Army Research Office.

1. "Bifurcation Analysis of Nonlinear Systems via Lyapunov-Floquet Technique", ARO Proposal Number: P-30509-EG-EPS (Grant Number: DAAL03-92-G-0364); Principal Investigator: Subhash C. Sinha, Dept. Of Mechanical Eng., Auburn University, AL 36849

2. "Analysis and Control of Parametrically Excited Dynamical Systems", ARO Proposal Number: P-33153-EG-DPS (Grant Number: DAAH04-94-G-0337); Principal Investigator: Subhash C. Sinha, Dept. Of Mechanical Engineering, Auburn University, AL 36849

Graduate Students & Research Personnel Using the Laboratory

1.	Subhash C. Sinha	Professor
2.	Ruxandra Botez	Post Doctoral Fellow
3.	R. Pandiyan	Ph.D. Student
4.	Eric Butcher	MS/Ph.D. Student
5.	Mike Spires	MS Student
6.	Dan Boghiu	Ph.D. Student

List of Publications

As of today 'Nonlinear Systems Research Laboratory' has been used to produce the following papers.

Pandiyan, R., and Sinha, S.C., 1995, "Periodic Flap Control of a Helicopter Blade in Forward Flight" submitted to *Journal of Vibration and Control.*

Spires, J.M., and Sinha, S.C., 1995, "On the Response of Linear Time-Periodic Systems Subjected to Deterministic and Stochastic Excitations" submitted to *Journal of Vibration and Control.*

Spires, J.M., and Sinha, S.C., 1995, "Response of Linear Time-Periodic Systems Subjected to Stochastic Excita-tions: A Chebyshev Polynomial Approach" to be presented at the Fifteenth ASME Biennial Conference on Mechanical Vibration and Noise, Sept. 17-21, 1995, Boston, MA, and to appear in the accompanying proceedings.

Spires, J.M., and Sinha, S.C.,1995, "Response of Time-Periodic Dynamical Systems Subjected to External Excita-tions" to be presented at the *International Conference on Structural Dynamics, Vibration, Noise and Control,* Hong Kong, December 5-7, 1995, and to appear in the accompanying proceedings.

Sinha, S.C., 1995, "Analysis of Time-Periodic Nonlinear Dynamical Systems," Invited talk; to be presented at the International Conference on Advances in Mechanical Engineering, December 20-22, 1995, Bangalore, India, and to appear in the accompanying proceedings.

Butcher, E. A., and Sinha, S.C., 1995, "On the Analysis of Time-Periodic Nonlinear Hamiltonian Dynamical Systems," to be presented at the Fifteenth ASME Biennial Conference on Mechanical Vibration and Noise, Sept. 17-21, 1995, Boston, MA, and to appear in the accompanying proceedings.

Sinha, S.C., and Butcher, E.A., 1995, "Solution and Stability of a Set of pth Order Linear Differential Equations with Periodic Coefficients via Chebyshev Polynomials," to appear in *Mathematical Problems in Engineering.*

Sinha, S.C., and Butcher, E.A., 1995, Authors' reply to "Some Observations on the Sinha Approach to Dynamic Response Calculations" by D.A. Peters, to appear in *J. Sound and Vibration.*

Butcher, E.A., and Sinha, S.C., 1995, "Transformations of Linear Hamiltonian Systems to Real Normal Forms via Permutation Matrices," submitted to *Celestial Mechanics and Dynamical Astronomy.*

Sinha, S.C., and Butcher, E.A., 1995, "A Hybrid Formulation for the Analysis of Time-Periodic Systems via Chebyshev Polynomials," submitted to *J. Sound and Vibration.*